# GPS III Arrived – An Initial Analysis of Signal Payload and Achieved User Performance

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DLR

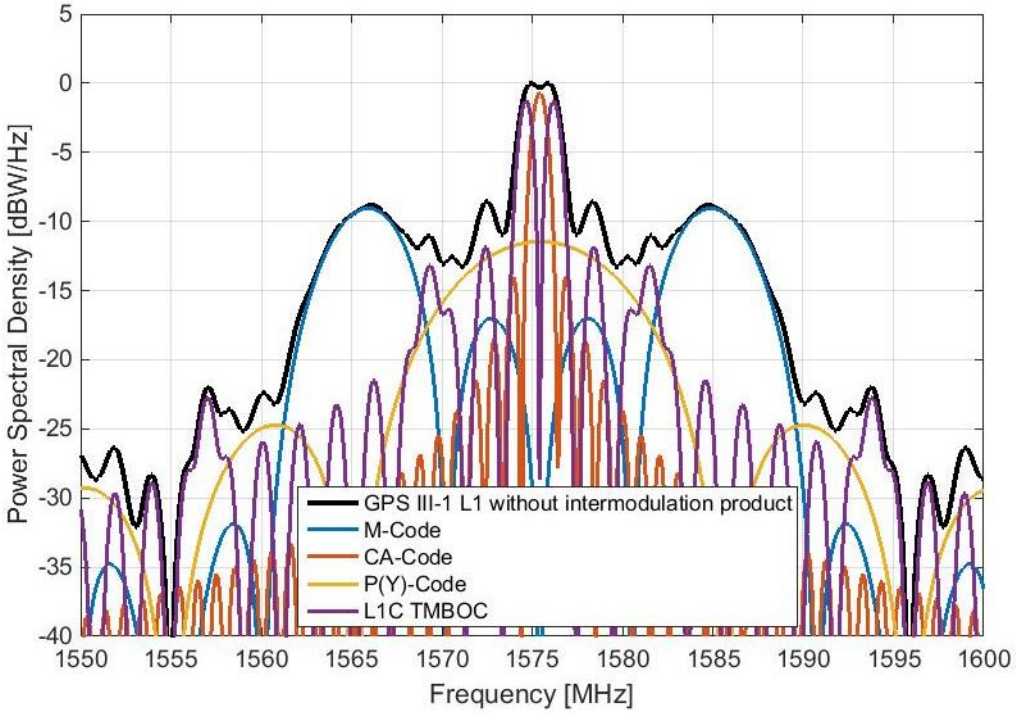
# Motivation

- GPS III-1 (SVN 74) is the first satellite of a new GPS generation
- New signal on board → L1C
- Signal quality comparing to previous GPS generations
- From the perspective of the user
  - Transmit & received power over elevation (satellite antenna pattern)
  - Signal deformation analysis (L1C, L5)
  - First multipath & noise and clock estimates

# Expectations / ICD

- Signals onboard of GPS III in L1 band

| Component | Modulation | Chipping rate [MHz] | Minimum received power [dBW] | Reference |
|---|---|---|---|---|
| C/A | BPSK(1) | 1.023 | –158.5 | IS-GPS-200J (2018) |
| L1C data | BOC(1,1) | 1.023 | –163.0 | IS-GPS-800E (2018) |
| L1C pilot | TMBOC(6,1,4/33) | 1.023 | –158.25 | IS-GPS-800E (2018) |
| P(Y) | BPSK(10) | 10.23 | –161.5 | IS-GPS-200J (2018) |
| M | BOC(10,5) | 10.23 | –158.0 | Marquis and Reigh (2015) |



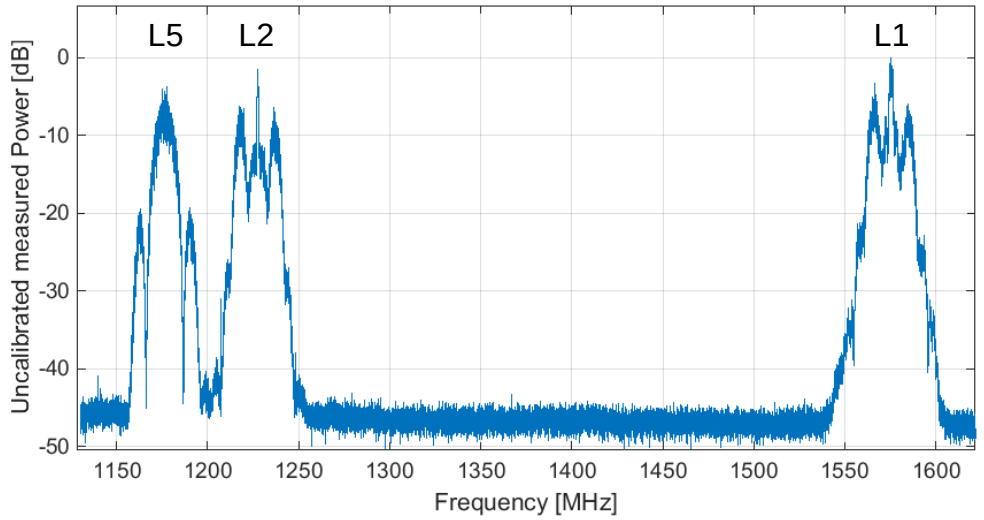

- How GPS manages the implementation of an additional signal on L1 band:
  - Interplexing: Majority voting of L1C (data+pilot) and P(Y)-code* in In-phase channel and C/A-code on Quadrature channel
  - What about M-code?

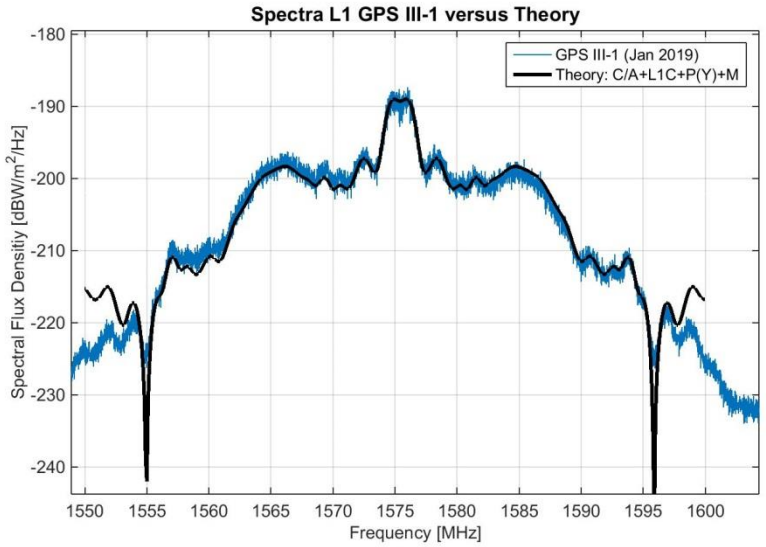
- L2 and L5 signals as known from GPS IIF

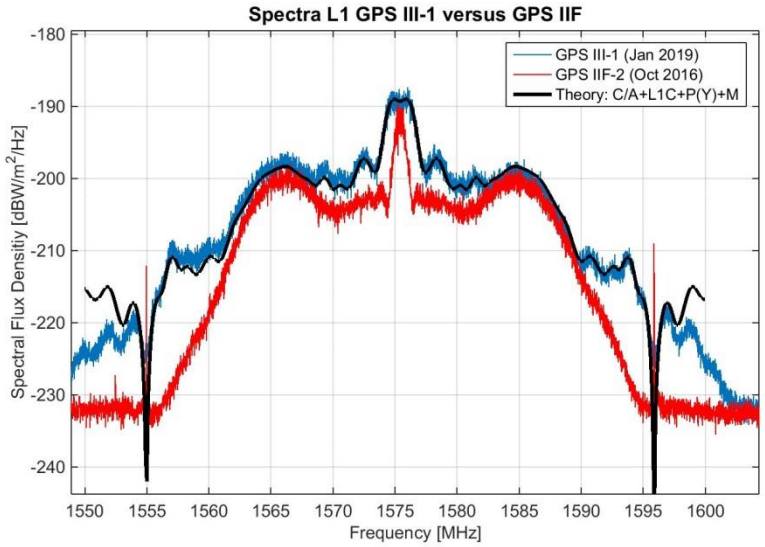
*Reference: D. Allen et.al. (2019) Effect of GPS III Weighted Voting on P(Y) Receiver Processing Performance. ION ITM 2019, Reston, USA


# Spectral view

- First signal transmission captured by GNSS receivers on January 9, 2019
- First spectral overview captured at ground station Weilheim, Germany on January 9, 2019 using a 30 m dish
- Measured L1 spectrum in comparison with the theory and GPS IIF

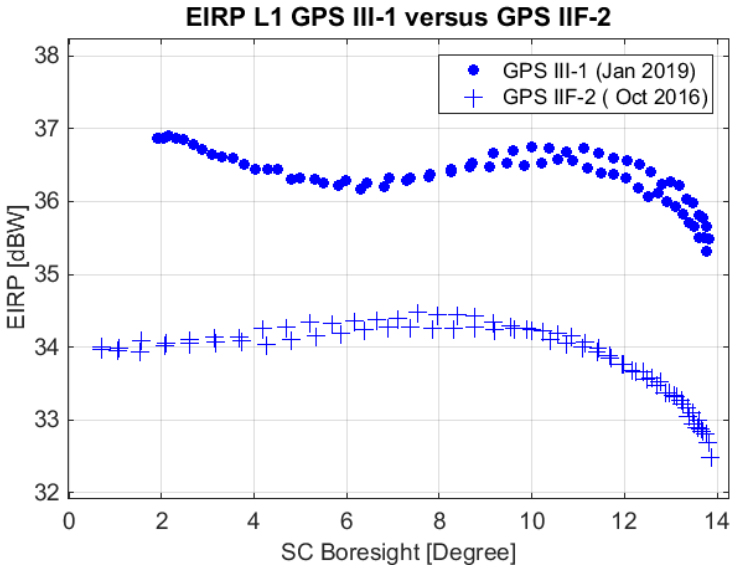


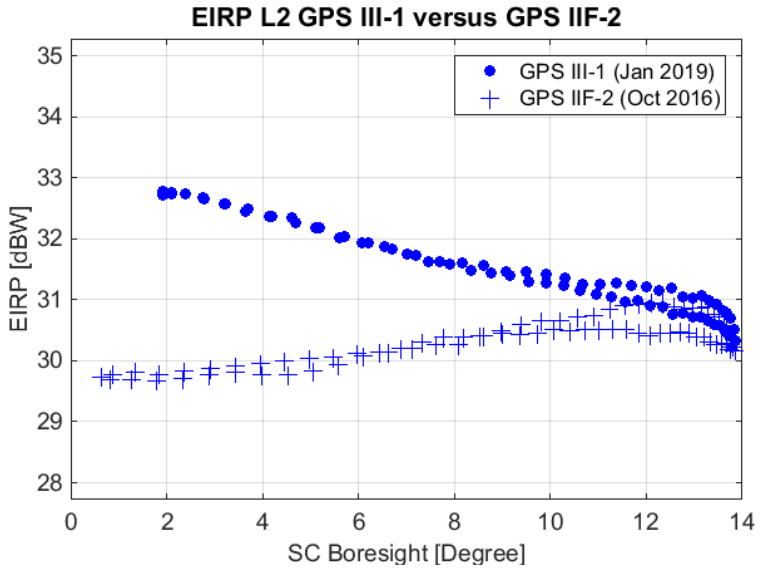



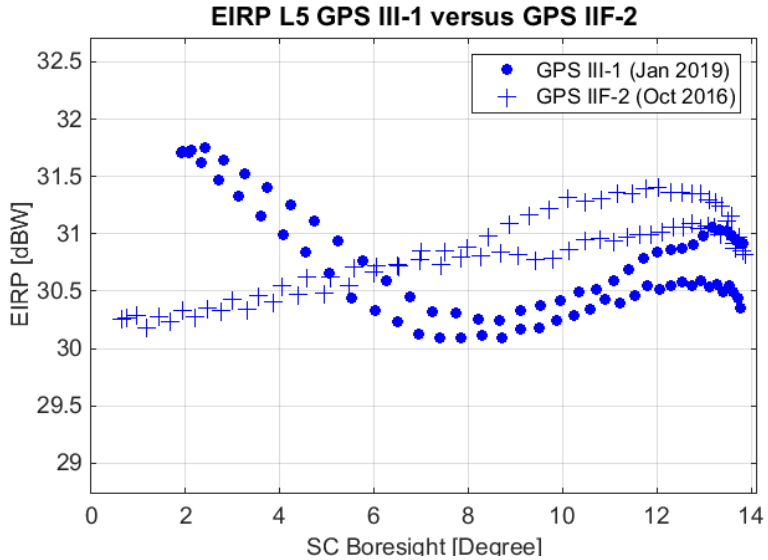




# Transmit Power - GPS IIF versus GPS III

- Equivalent isotropic radiated power (EIRP) measured at Weilheim, Germany
- Considered satellites: GPS III-1 and GPS IIF-2
- Data captured every 5 minutes at Weilheim ground station over a full satellite pass



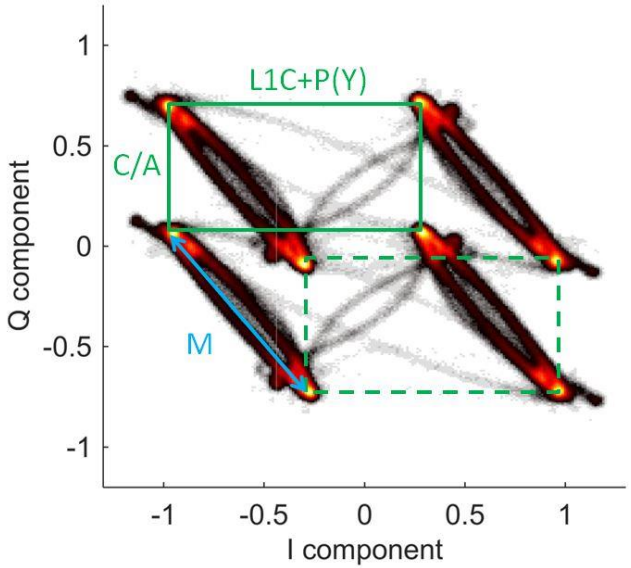



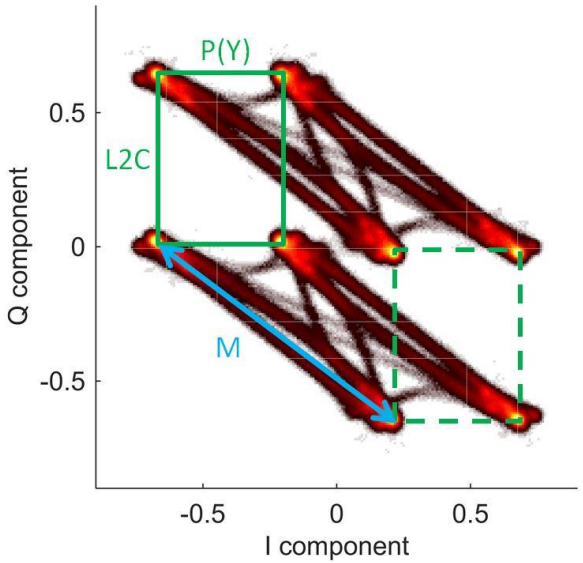



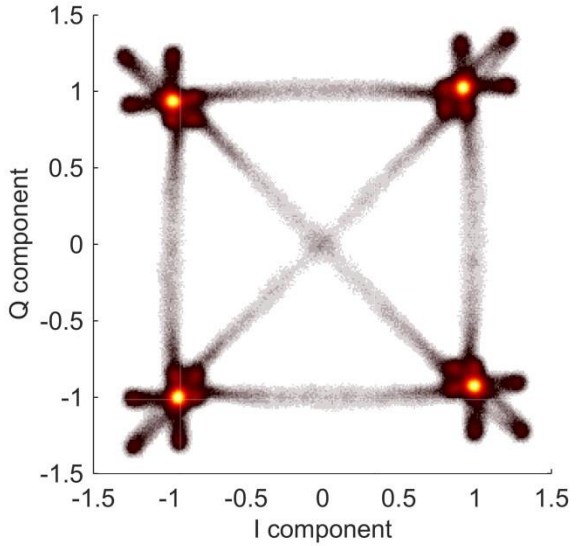

- Different pattern shapes can be observed for all frequency bands. What could be the origin?

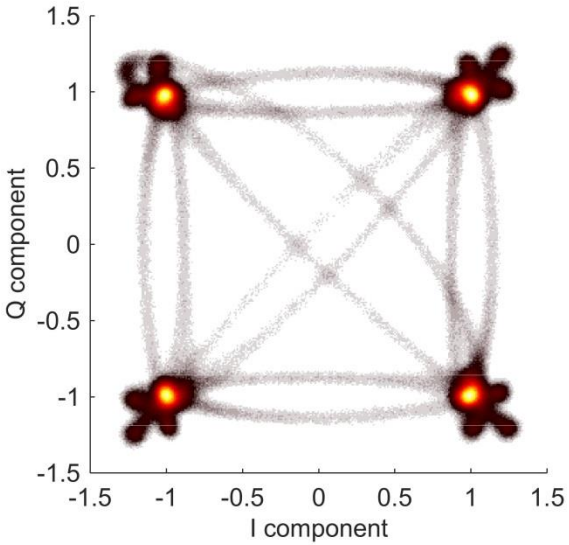
# Inphase (I) & Quadrature (Q) Data Constellation View

| GPS III-1 | | | GPS IIF-1 |
|---|---|---|---|
| L1 | L2 | L5 | L5 |



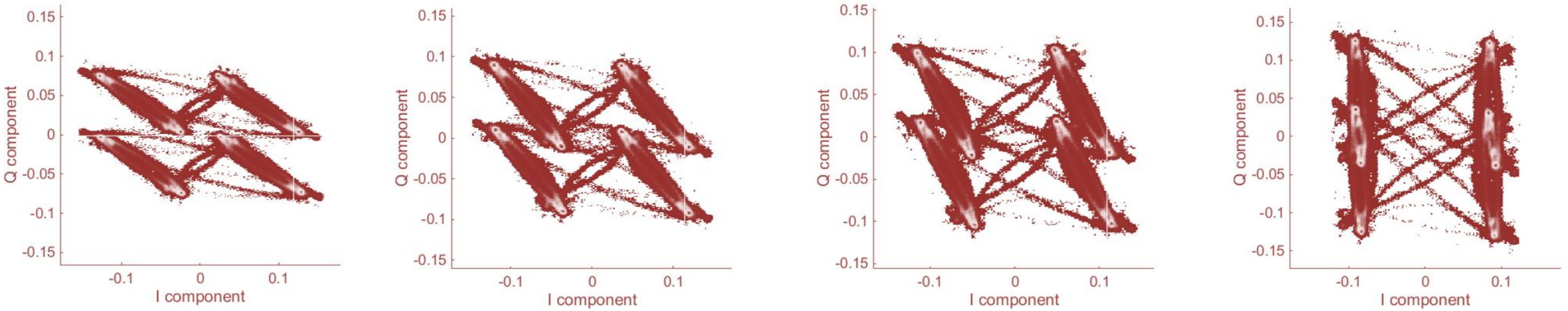




- Constellation plots show good signal quality in terms of possible signal distortions based on their clear constellation points and almost straight chip transitions for GPS III-1.

# Inphase (I) & Quadrature (Q) Data Constellation View

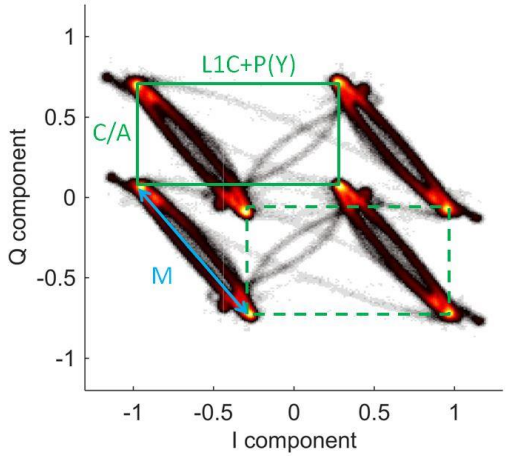
- GPS III-1 L1 IQ constellation over measurement time
- M-Code phase relation according to other L1 signals changes over elevation (measurement time)

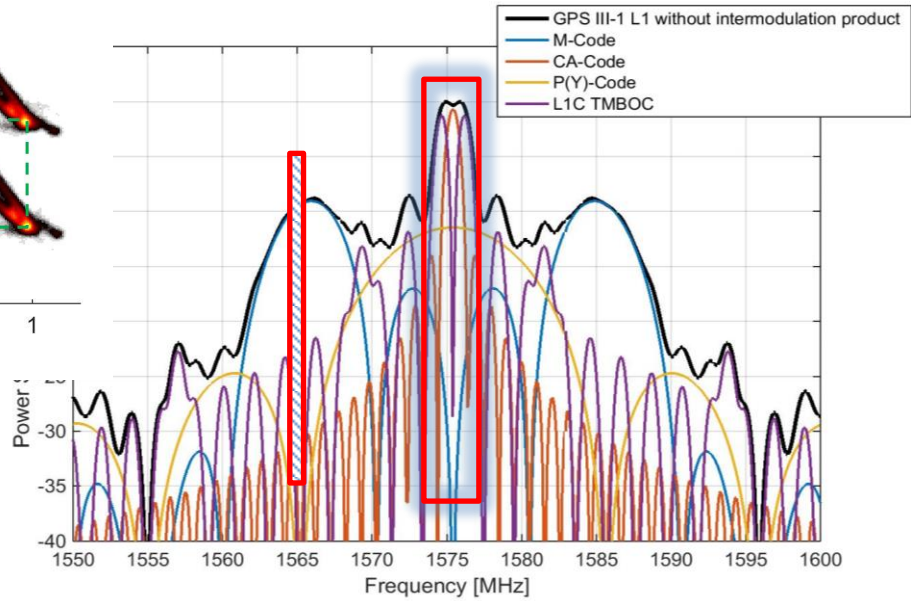


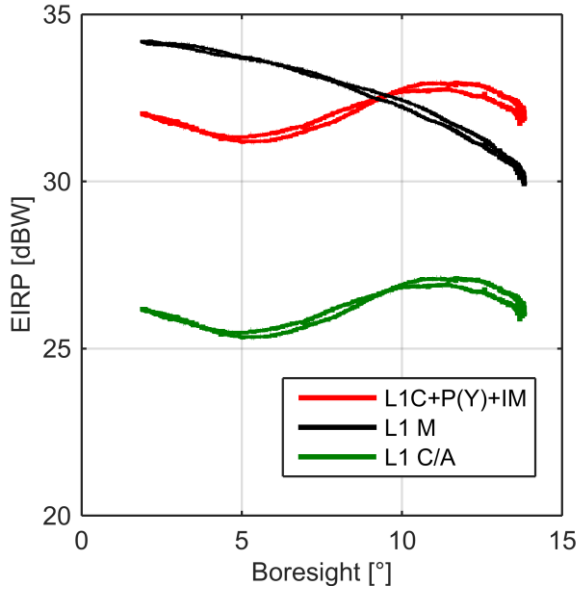

- Conclusion: M-code transmission not via same antenna network as for the other L1 signals (C/A, P(Y)+L1C)

# L1 Gain Patterns of individual Components

- IQ constellation provides amplitude relation between C/A-code, L1C+P(Y)-code and M-code
- Spectra over time provide power relation over time. For separation purposes, one can use a part only with M-code and another one only with P(Y)+L1C respectively C/A-code (illustrated by the red boxes).
- Combining IQ constellation and transmit power information over time, one can separate gain patterns for L1 C/A-, M- and L1C+P(Y) components



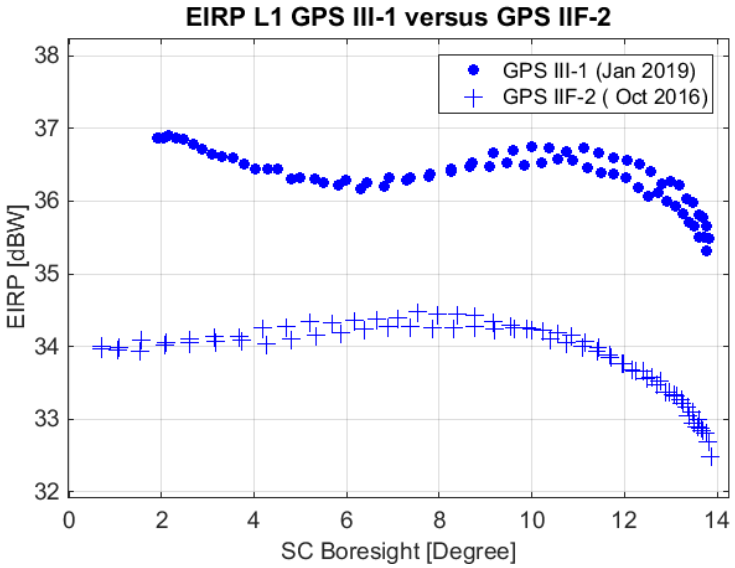



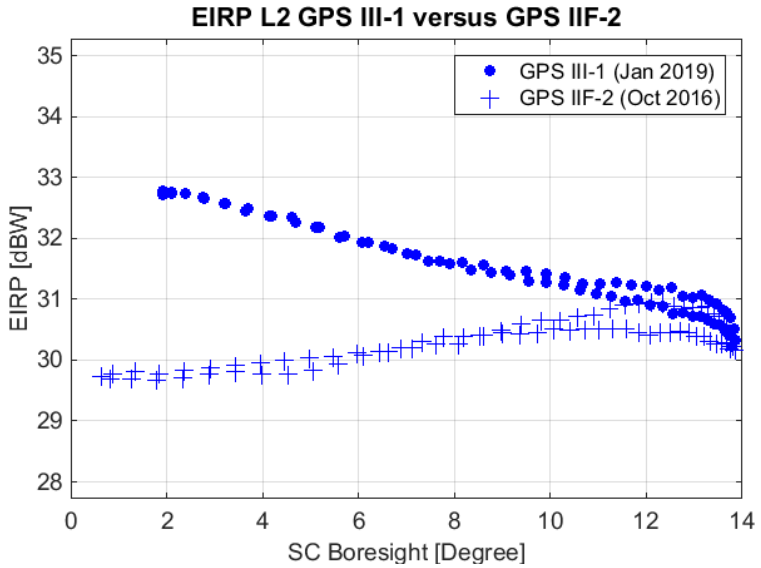



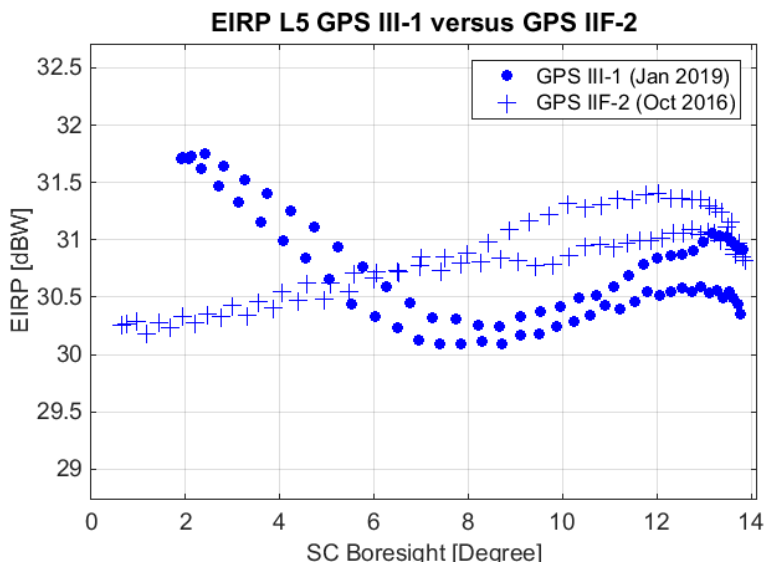

M-code is transmitted via a seperate antenna or at least using only a part of the antenna network used for the rest of the L1 signals

# Transmit Power - GPS IIF versus GPS III

- Conclusions of IQ constellation and power spectra analysis regarding transmit pattern of GPS III:
  - L1: Superposition of C/A+P(Y)+L1C antenna network and M-code antenna network with different gain patterns
  - L2: Superposition of P(Y)+L2C antenna network and M-code antenna network with different gain patterns
  - L5: Seems to be a new antenna



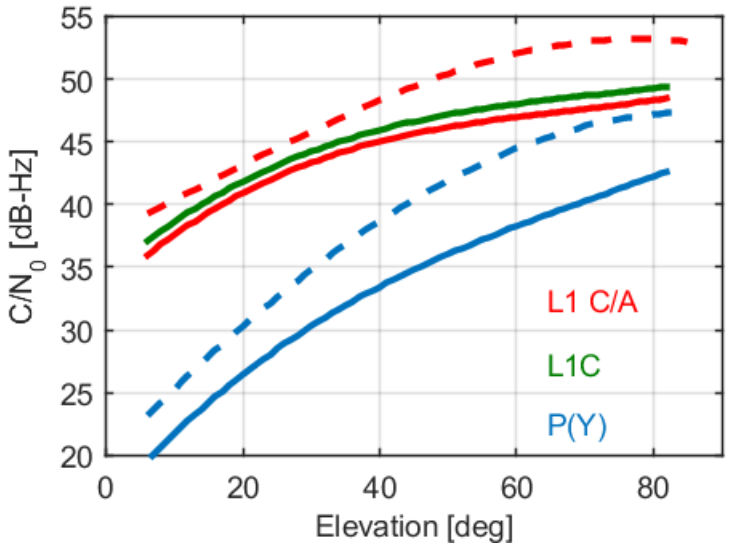



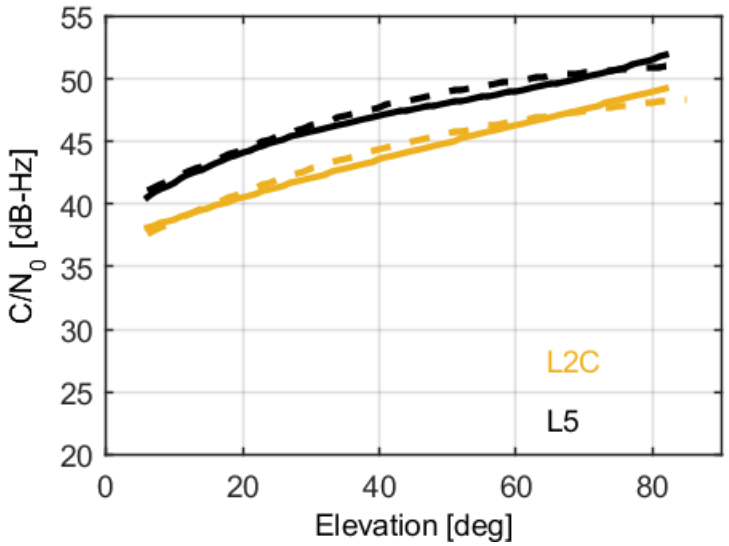




- What does the transmitted power mean for users and their signal strength reception?

# Signal strength from the perspective of the user

- Carrier-to-noise density ratio of GPS signals tracked by a Septentrio PolaRx5 receiver with a Leica AR1203+GNSS antenna in Oberpfaffenhofen, Germany.




Legend:
GPS III-1 (solid line)

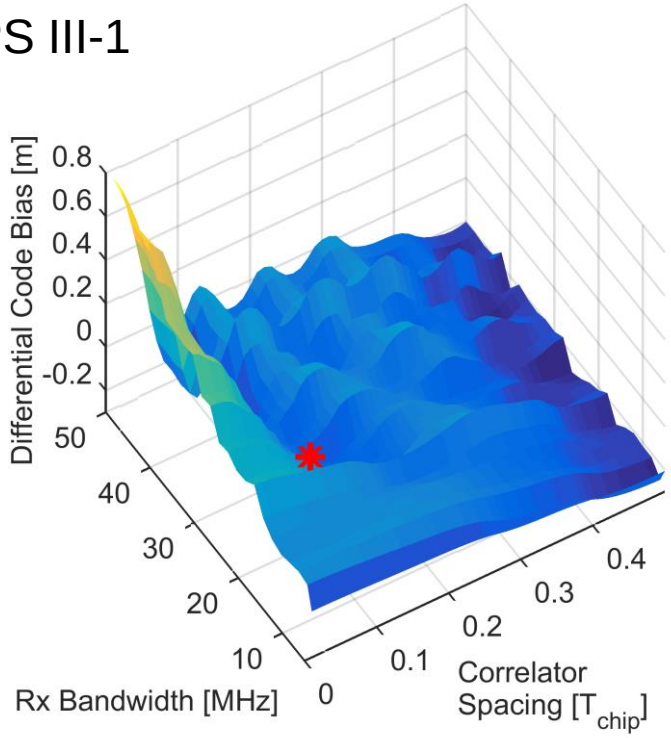
GPS Block IIF satellite (SVN 68, dashed line)

- Measured minimum received power for L1 C/A-code of -157.9 dBW at 5° elevation (ICD -158.5 dBW)

# Signal Deformation & Differential Code Bias Estimation: L1 band

- Performance of the new GPS L1C signal in differential GNSS applications, like Ground Based Augmentation Systems (GBAS)
- Differential code bias estimation GPS III-1 L1C versus Galileo E1C based on S-curve bias method

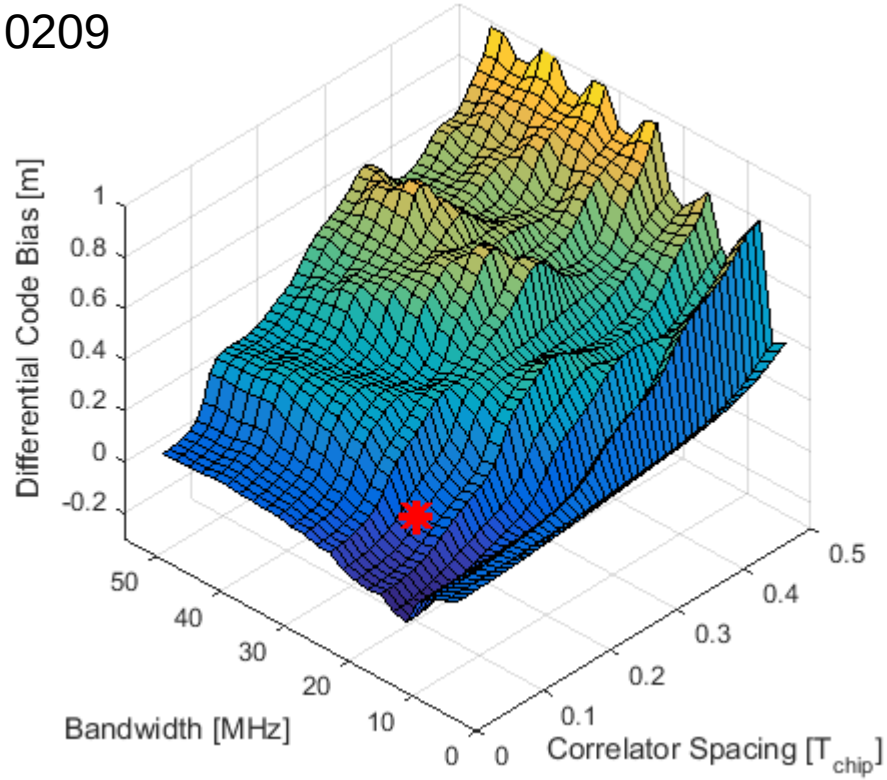
GPS III-1




✳ Reference Receiver settings based on the current draft MOPS for aviation applications:

Spacing = 0.1 chip
Bandwidth = 24 MHz

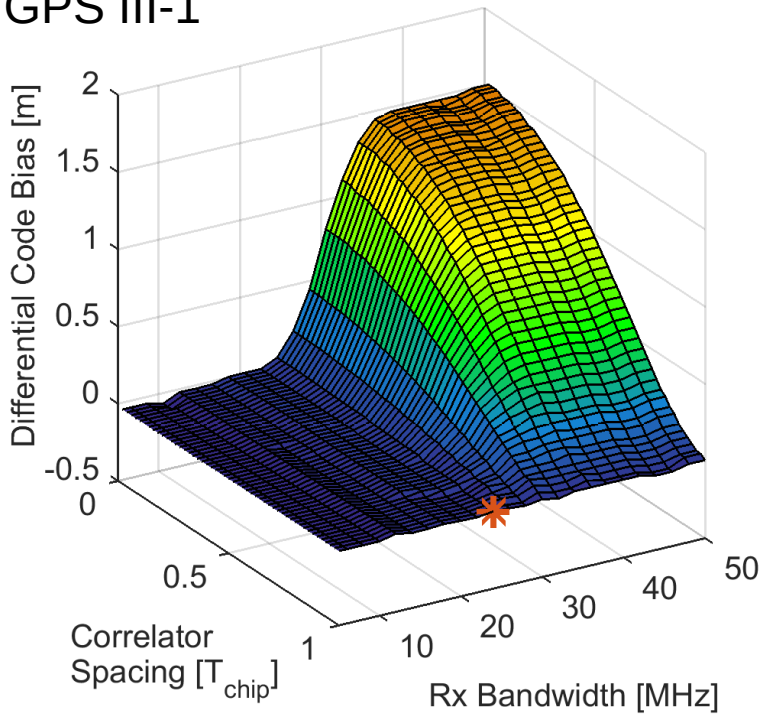
GSAT 0209



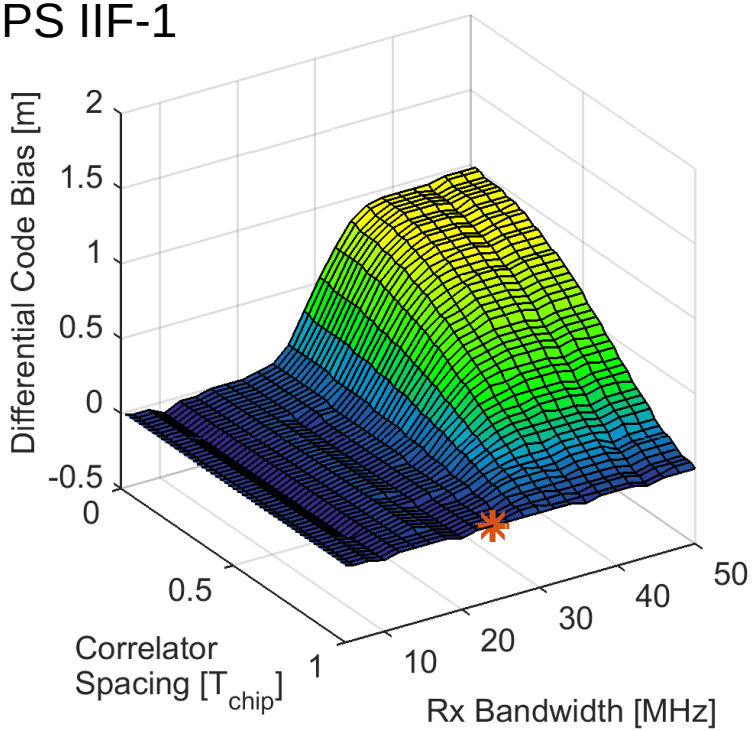
# Signal Deformation & Differential Code Bias Estimation: L5 band

- Differential code bias estimates for GPS III-1 versus GPS IIF-1 for L5 pilot

GPS III-1




GPS IIF-1




| | Digital distortions [ns] | |
|---|---|---|
| **Signal** | GPS IIF-1 | GPS III-1 |
| **L5 data** | 5.1 | 0.2 |
| **L5 pilot** | 3.6 | 0.4 |

✳ Reference Receiver settings based on the current draft MOPS for aviation applications:

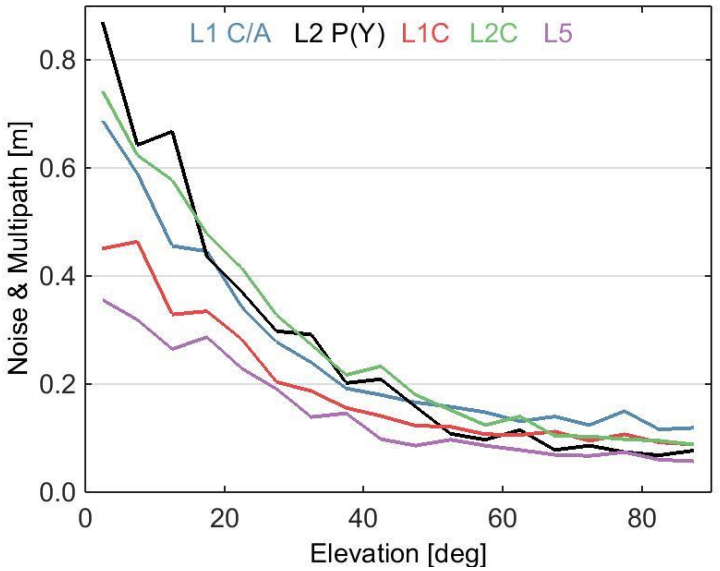
Spacing = 1 chip
Bandwidth = 24 MHz

- Very low differential biases up to 25 MHz input bandwidth and a wide range of correlator spacing for both GPS satellites

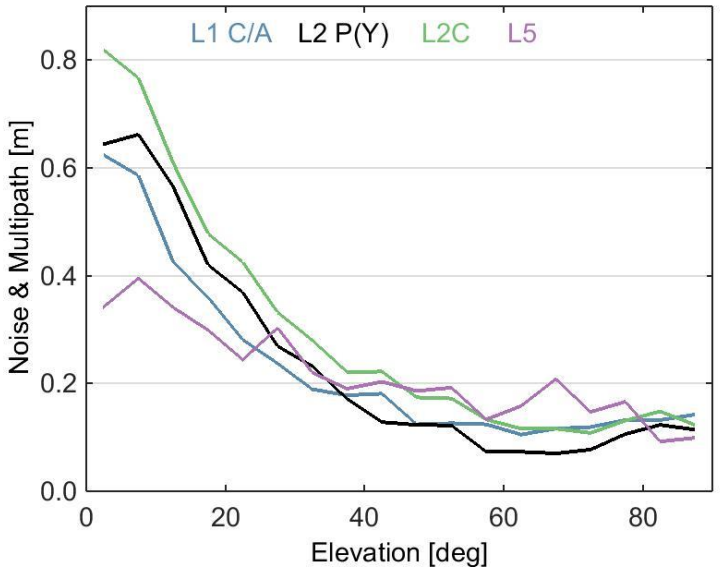
# Receiver Tracking: Multipath & Noise

- Multipath & noise estimation based on Javad TR_3 receiver data from IGS station (POTS00DEU) at Potsdam, Germany

GPS III-1 (G04)




GPS IIF-7 (G09)




- Multipath combination

$$\mathrm{MP}(p_i, \varphi_i, \varphi_j) = p_i - \varphi_i - 2\frac{f_j^2}{f_i^2 - f_j^2}(\varphi_i - \varphi_j)$$

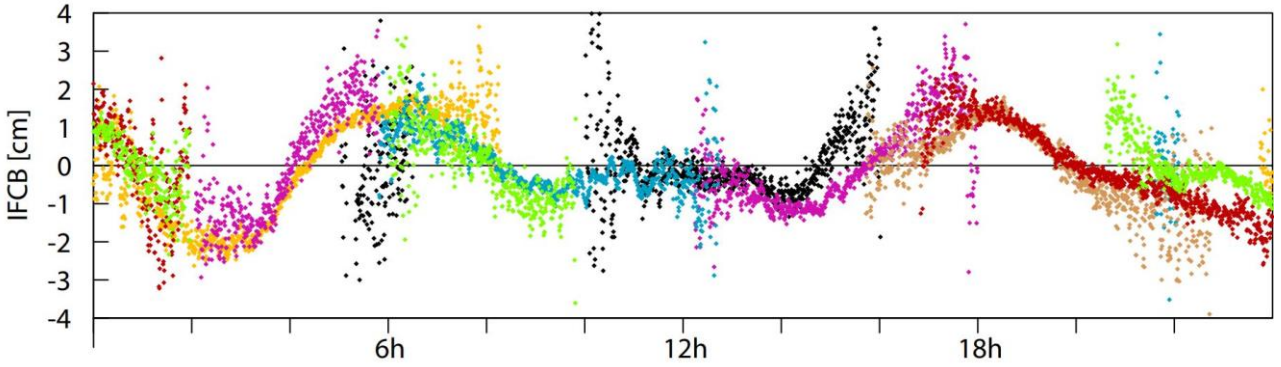
$p_i$ pseudorange observations
$\varphi_i, \varphi_j$ carrier phase observations
$i, j$ frequency index: $i, j = 1,2,5$

- RMS in 5 deg elevation bins

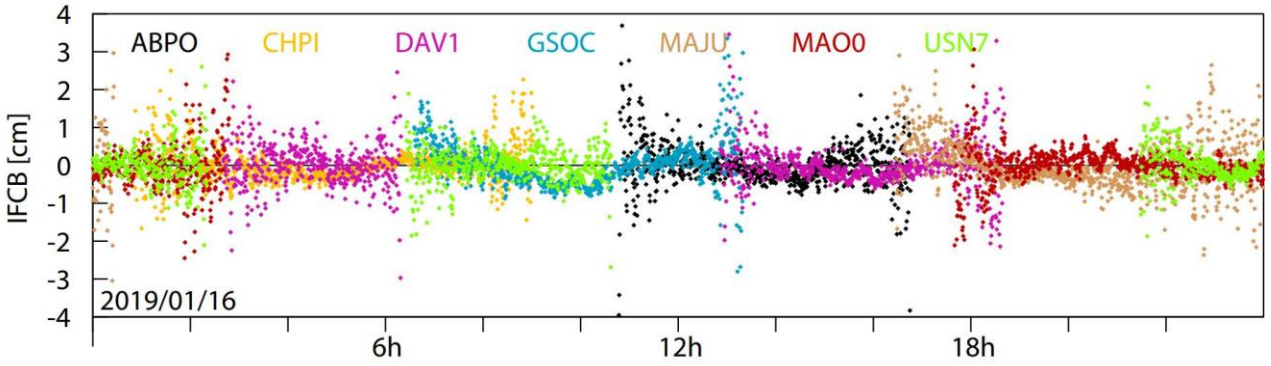
# Interfrequency Clock Bias (IFCB)

- Interfrequency clock bias estimation based on triple carrier phase observations using measurements of 7 stations
- For lower elevations the triple carrier phase combination is dominated by noise and multipath
- Results:
  - Block IIF: small orbit-periodic variations can be seen for the Block IIF satellite (within cm-range, peak-to-peak approx. 4 cm)
  - Block III: no orbit periodic variations

GPS IIF (SVN 68)

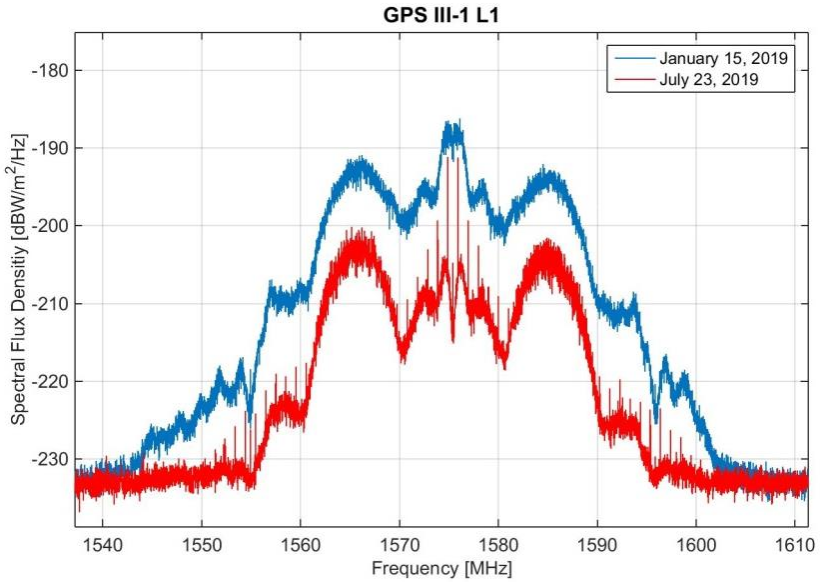


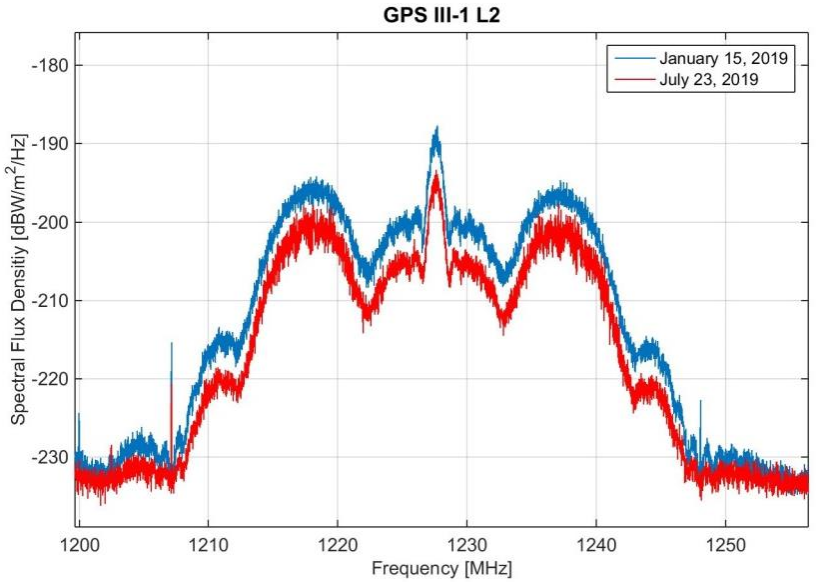

GPS III (SVN 74)

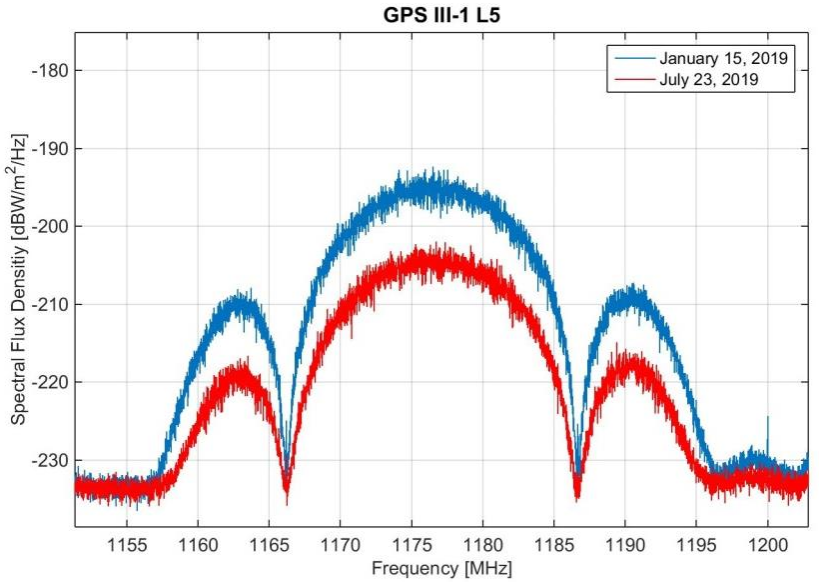


# GPS III-1 current signal status (August 2019)

- Reduced transmit power on all 3 bands




- Instead of nominal C/A-code the non-standard code is transmitted on L1

- L1C PRN moved from 4 to 117, L5 PRN has also moved


# Conclusion and Outlook

- The new GPS III generation has started signal transmission
- The new signal L1C is present and shows good quality in terms of signal distortions and noise & multipath characteristics
- M-code transmission is partially separated from other signals  on L1 and L2
- Minimum received power for L1 C/A-code is in line with ICD, but with low margin to its proposed minimum
- L5 signal has comparable signal distortions to GPS IIF block satellites
- Good consistency of L1/L2/L5 carriers, no signs of orbit dependent interfrequency bias variations
- Currently the GPS III-1 uses non-operational signal transmission



# Thank you for your attention – Any questions?